$B \to \pi\pi$, New Physics in $B \to \pi K$, and Implications for Rare K and B Decays

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The measured $B \to \pi\pi, \pi K$ branching ratios (BRs) exhibit puzzling patterns. We point out that the $B \to \pi\pi$ hierarchy can be nicely accommodated in the standard model (SM) through nonfactorizable hadronic interference effects, whereas the $B \to \pi K$ system may indicate new physics (NP) in the electroweak (EW) penguin sector. Using the $B \to \pi\pi$ data and the SU(3) flavor symmetry, we fix the hadronic $B \to \pi K$ parameters and show that any currently observed feature of the $B \to \pi K$ system can be easily explained through enhanced EW penguin diagrams with a large CP-violating NP phase. This in turn implies in particular an enhancement of the $K_L \to \pi^0 \nu\bar{\nu}$ rate by 1 order of magnitude, with $\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu}) \approx 4\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})$, $\mathrm{BR}(K_L \to \pi^0 e^+ e^-) = O(10^{-10})$, and $(\sin 2\beta)_{\pi\nu\bar{\nu}} < 0$. We address also other rare K and B decays and $B_d \to \phi K_S$.

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In this Letter, we consider simultaneously the decays $B \to \pi\pi$, $B \to \pi K$ and prominent rare K and B decays within the standard model (SM) and its simple extension in which new physics (NP) enters dominantly through enhanced electroweak (EW) penguin diagrams with new weak phases. Our analysis consists of three interrelated parts and has the following logical structure:

(i) Since $B \to \pi\pi$ decays and the usual analysis of the unitarity triangle (UT) are only insignificantly affected by EW penguin diagrams, the $B \to \pi\pi$ system can be described as in the SM and allows the extraction of the relevant hadronic parameters by assuming only the isospin symmetry. The values of these parameters imply important nonfactorizable contributions and allow us to predict the CP-violating $B_d \to \pi^0\pi^0$ observables.

(ii) Using the SU(3) flavor symmetry and plausible dynamical assumptions, we may determine the hadronic $B \to \pi K$ parameters through their $B \to \pi\pi$ counterparts and may analyze the $B \to \pi K$ system in the SM. Interestingly, those observables where EW penguin diagrams play a minor role are found to agree with the pattern of the B-factory data. On the other hand, the observables that are significantly affected by EW penguin diagrams are found to disagree with the experimental picture, thereby suggesting NP in the EW penguin sector. Indeed, we may describe all the currently available data through sizably enhanced EW penguin diagrams with a large CP-violating NP phase around $-90°$ and may then predict the CP-violating $B_d \to \pi^0 K_S$ observables. We also obtain insights into SU(3)-breaking effects, which support our working assumptions, and determine the UT angle γ, in accordance with the well-known UT fits.

(iii) In turn, the enhanced EW penguin diagrams, with their large CP-violating NP phases, have important implications for rare K and B decays, with several predictions significantly different from the SM expectations.

This Letter summarizes the most interesting results of each step. The details behind the findings presented here are described in [1], where the arguments for the assumptions made in our analysis are spelled out, other results are presented, and a detailed list of references is given.

The BaBar and Belle Collaborations have very recently reported the observation of $B_d \to \pi^0\pi^0$ decays with CP-averaged branching ratios (BRs) of $(2.1 \pm 0.6 \pm 0.3) \times 10^{-6}$ and $(1.7 \pm 0.6 \pm 0.2) \times 10^{-6}$, respectively [2,3]. These measurements represent quite a challenge for theory. For example, in a recent state-of-the-art calculation within QCD factorization [4], a branching ratio that is about 6 times smaller is favored, whereas the calculation of $B_d \to \pi^+\pi^-$ points towards a branching ratio about 2 times larger than the current experimental average. On the other hand, the calculation of $B^+ \to \pi^+\pi^0$ reproduces the data rather well. This "$B \to \pi\pi$ puzzle" is reflected by the following quantities:

$$R_{+-}^{\pi\pi} \equiv 2\left[\frac{\mathrm{BR}(B^\pm \to \pi^\pm\pi^0)}{\mathrm{BR}(B_d \to \pi^+\pi^-)}\right]\frac{\tau_{B_d^0}}{\tau_{B^+}} = 2.12 \pm 0.37, \quad (1)$$

$$R_{00}^{\pi\pi} \equiv 2\left[\frac{\mathrm{BR}(B_d \to \pi^0\pi^0)}{\mathrm{BR}(B_d \to \pi^+\pi^-)}\right] = 0.83 \pm 0.23, \quad (2)$$

where we have used the most recent compilation of the Heavy Flavour Averaging Group [5]; the central values calculated within QCD factorization [4] give $R_{+-}^{\pi\pi} = 1.24$ and $R_{00}^{\pi\pi} = 0.07$. In order to simplify our $B \to \pi\pi$ analysis, we neglect EW penguin diagrams, which play a minor role here and can be straightforwardly included through the isospin symmetry [1,6,7]. We then have

$$\sqrt{2}A(B^+ \to \pi^+\pi^0) = -[\tilde{T} + \tilde{C}], \quad (3)$$

$$A(B_d^0 \to \pi^+\pi^-) = -[\tilde{T} + P], \quad (4)$$

$$\sqrt{2}A(B_d^0 \to \pi^0\pi^0) = -[\tilde{C} - P], \tag{5}$$

$$P = \lambda^3 A(\mathcal{P}_t - \mathcal{P}_c) \equiv \lambda^3 A \mathcal{P}_{tc}, \tag{6}$$

$$\tilde{T} = \lambda^3 A R_b e^{i\gamma}[\mathcal{T} - (\mathcal{P}_{tu} - \mathcal{E})], \tag{7}$$

$$\tilde{C} = \lambda^3 A R_b e^{i\gamma}[C + (\mathcal{P}_{tu} - \mathcal{E})]. \tag{8}$$

Here λ, A, and $R_b \propto |V_{ub}/V_{cb}|$ parametrize the Cabibbo-Kobayashi-Maskawa matrix, the $\mathcal{P}_q$ are the strong amplitudes of QCD penguin diagrams with internal q-quark exchanges ($q \in \{t, c, u\}$), including annihilation and exchange penguin diagrams, while $\mathcal{T}$ and C are the strong amplitudes of color-allowed and color-suppressed tree-diagram-like topologies, respectively, and $\mathcal{E}$ denotes exchange topologies. Introducing the hadronic parameters

$$de^{i\theta} \equiv -e^{i\gamma}P/\tilde{T} = -|P/\tilde{T}|e^{i(\delta_P - \delta_{\tilde{T}})}, \tag{9}$$

$$xe^{i\Delta} \equiv \tilde{C}/\tilde{T} = |\tilde{C}/\tilde{T}|e^{i(\delta_{\tilde{C}} - \delta_{\tilde{T}})}, \tag{10}$$

with the strong phases δ_P, $\delta_{\tilde{T}}$, and $\delta_{\tilde{C}}$, we obtain

$$R_{+-}^{\pi\pi} = \frac{1 + 2x\cos\Delta + x^2}{1 - 2d\cos\theta\cos\gamma + d^2}, \tag{11}$$

$$R_{00}^{\pi\pi} = \frac{d^2 + 2dx\cos(\Delta - \theta)\cos\gamma + x^2}{1 - 2d\cos\theta\cos\gamma + d^2}, \tag{12}$$

$$\mathcal{A}_{CP}^{\text{dir}} = -\left[\frac{2d\sin\theta\sin\gamma}{1 - 2d\cos\theta\cos\gamma + d^2}\right], \tag{13}$$

$$\mathcal{A}_{CP}^{\text{mix}} = \frac{\sin(\phi_d + 2\gamma) - 2d\cos\theta\sin(\phi_d + \gamma) + d^2\sin\phi_d}{1 - 2d\cos\theta\cos\gamma + d^2}, \tag{14}$$

where ϕ_d denotes the B_d^0-$\bar{B}_d^0$ mixing phase and $\mathcal{A}_{CP}^{\text{dir}}$ and $\mathcal{A}_{CP}^{\text{mix}}$ are the direct and mixing-induced $B_d \to \pi^+\pi^-$ CP asymmetries [8,9]. The available BaBar [10] and Belle [11] results for $\mathcal{A}_{CP}^{\text{dir}}(\pi^+\pi^-)$ and $\mathcal{A}_{CP}^{\text{mix}}(\pi^+\pi^-)$ are not fully consistent with each other. If one calculates, nevertheless, the weighted averages, one finds [5]

$$\begin{aligned} \mathcal{A}_{CP}^{\text{dir}}(\pi^+\pi^-) &= -0.38 \pm 0.16, \\ \mathcal{A}_{CP}^{\text{mix}}(\pi^+\pi^-) &= 0.58 \pm 0.20. \end{aligned} \tag{15}$$

As pointed out in [9,12], in the case of $\phi_d \sim 47°$, the CP asymmetries in (15) point towards $\gamma \sim 60°$, in accordance with the SM. In the following, our main focus is on the hadronic parameters. If we assume that $\gamma = (65 \pm 7)°$ and $\phi_d = 2\beta = (47 \pm 4)°$, as in the SM [13], (11)–(14) and the data in (1), (2), and (15) imply

$$\begin{aligned} d &= 0.49^{+0.33}_{-0.21}, & \theta &= +(137^{+19}_{-23})°, \\ x &= 1.22^{+0.25}_{-0.21}, & \Delta &= -(71^{+19}_{-25})°, \end{aligned} \tag{16}$$

where we have suppressed a second solution for (x, Δ), which does not allow us to accommodate the $B \to \pi K$ data [1]. This determination is essentially theoretically clean, and the experimental picture will improve significantly in the future. We observe that $x = O(1)$, which implies $|\tilde{C}| \sim |\tilde{T}|$. In view of the anticipated color suppression of C with respect to $\mathcal{T}$, this can be satisfied only if the usually neglected contributions $(\mathcal{P}_{tu} - \mathcal{E})$ in Eqs. (7) and (8) are significant [14]. Indeed, because of the different signs in Eqs. (7) and (8), we may explain the surprisingly small $B_d \to \pi^+\pi^-$ branching ratio naturally, through *destructive* interference between the $\mathcal{T}$ and $(\mathcal{P}_{tu} - \mathcal{E})$ amplitudes, whereas the puzzling large $B_d \to \pi^0\pi^0$ branching ratio originates from *constructive* interference between the C and $(\mathcal{P}_{tu} - \mathcal{E})$ amplitudes. Within factorization, $B_d \to \pi^+\pi^-$ would favor $\gamma > 90°$, in contrast to the SM expectation, thereby reducing BR$(B_d \to \pi^+\pi^-)$ through destructive interference between tree and penguin diagrams. Now we arrive at a picture that is very different from factorization and exhibits certain interference effects at the hadronic level; this allows us to accommodate straightforwardly *any* currently observed feature of the $B \to \pi\pi$ system within the SM. Moreover, we *predict* the CP-violating $B_d \to \pi^0\pi^0$ observables [1]:

$$\begin{aligned} \mathcal{A}_{CP}^{\text{dir}}(\pi^0\pi^0) &= -0.40^{+0.35}_{-0.18}, \\ \mathcal{A}_{CP}^{\text{mix}}(\pi^0\pi^0) &= -0.56^{+0.43}_{-0.44}. \end{aligned} \tag{17}$$

In the $B \to \pi K$ system, the following ratios of CP-averaged branching ratios are of central interest [6]:

$$R_{\text{c}} \equiv 2\left[\frac{\text{BR}(B^\pm \to \pi^0 K^\pm)}{\text{BR}(B^\pm \to \pi^\pm K^0)}\right] = 1.17 \pm 0.12, \tag{18}$$

$$R_{\text{n}} \equiv \frac{1}{2}\left[\frac{\text{BR}(B_d \to \pi^\mp K^\pm)}{\text{BR}(B_d \to \pi^0 K)}\right] = 0.76 \pm 0.10, \tag{19}$$

with numerical values following from [5]. As noted in [15], the pattern of $R_{\text{c}} > 1$ and $R_{\text{n}} < 1$ is actually very puzzling. On the other hand,

$$R \equiv \left[\frac{\text{BR}(B_d \to \pi^\mp K^\pm)}{\text{BR}(B^\pm \to \pi^\pm K)}\right]\frac{\tau_{B^+}}{\tau_{B_d^0}} = 0.91 \pm 0.07 \tag{20}$$

does not show any anomalous behavior. Since R_{c} and R_{n} are affected significantly by color-allowed EW penguin diagrams, whereas these topologies may only contribute in color-suppressed form to R, this "$B \to \pi K$ puzzle" may be a manifestation of NP in the EW penguin sector [15,16], offering an attractive avenue for physics beyond the SM to enter the $B \to \pi K$ system [17].

In this Letter, we neglect color-suppressed EW penguin diagrams, employ SU(3) flavor-symmetry arguments, and assume that penguin annihilation and exchange topologies are small. The latter topologies can be probed through $B_d \to K^+K^-$, where the current experimental bound of BR$(B_d \to K^+K^-) < 0.6 \times 10^{-6}$(90%C.L.) [5] does not indicate any anomalous behavior [1]. We then go beyond [16] in two respects. First, we employ the $B \to \pi\pi$ data to fix the hadronic parameters of the $B \to \pi K$

system. Second, we consider CP-violating NP contributions to the EW penguin sector, so that these topologies are described by a parameter q with a CP-violating weak phase ϕ, which vanishes in the SM. We may then write

$$A(B_d^0 \to \pi^- K^+) = P'[1 - re^{i\delta}e^{i\gamma}], \tag{21}$$

$$\sqrt{2}A(B_d^0 \to \pi^0 K^0) = -P'[1 + \rho_{\rm n}e^{i\theta_{\rm n}}e^{i\gamma} - qe^{i\phi}r_{\rm c}e^{i\delta_{\rm c}}], \tag{22}$$

where $P' \equiv (1 - \lambda^2/2)A\lambda^2(\mathcal{P}_t - \mathcal{P}_c)$ is the counterpart of (6), and the $B \to \pi\pi$ analysis described above allows us to fix the hadronic $B \to \pi K$ parameters through [1]

$$re^{i\delta} \equiv \left(\frac{\lambda^2 R_b}{1-\lambda^2}\right)\left[\frac{\mathcal{T} - (\mathcal{P}_t - \mathcal{P}_u)}{\mathcal{P}_t - \mathcal{P}_c}\right] = -\frac{\epsilon}{de^{i\theta}}, \tag{23}$$

$$\rho_{\rm n}e^{i\theta_{\rm n}} \equiv \left(\frac{\lambda^2 R_b}{1-\lambda^2}\right)\left[\frac{\mathcal{C} + (\mathcal{P}_t - \mathcal{P}_u)}{\mathcal{P}_t - \mathcal{P}_c}\right] = xe^{i\Delta}re^{i\delta}, \tag{24}$$

$$r_{\rm c}e^{i\delta_{\rm c}} \equiv \left(\frac{\lambda^2 R_b}{1-\lambda^2}\right)\left[\frac{\mathcal{T} + \mathcal{C}}{\mathcal{P}_t - \mathcal{P}_c}\right] = re^{i\delta} + \rho_{\rm n}e^{i\theta_{\rm n}}, \tag{25}$$

where $\epsilon \equiv \lambda^2/(1-\lambda^2) = 0.05$. Consequently, Eq. (16) yields

$$\begin{aligned} r &= 0.11^{+0.06}_{-0.05}, & \delta &= +(43^{+23}_{-19})^\circ,\\ \rho_{\rm n} &= 0.13^{+0.06}_{-0.05}, & \theta_{\rm n} &= -(28^{+21}_{-26})^\circ,\\ r_{\rm c} &= 0.20^{+0.09}_{-0.07}, & \delta_{\rm c} &= +(3^{+23}_{-18})^\circ, \end{aligned} \tag{26}$$

where the errors have been added in quadrature. We observe that $re^{i\delta}$ and $\rho_{\rm n}e^{i\theta_{\rm n}}$ differ strongly from factorization. However, the small value of r implies generically small CP violation in $B_d \to \pi^\mp K^\pm$ at the 10% level [1], in accordance with the data [5]. Interestingly, the value of $r_{\rm c}$ agrees well with the one of an alternative determination through $B^\pm \to \pi^\pm\pi^0, \pi^\pm K$ decays [18], 0.196 ± 0.016, thereby pointing towards moderate nonfactorizable SU(3)-breaking corrections. Neglecting a small parameter $\rho_{\rm c}e^{i\theta_{\rm c}} \propto \lambda^2 R_b$ [1], we may write

$$A(B^+ \to \pi^+ K^0) = -P', \tag{27}$$

$$\sqrt{2}A(B^+ \to \pi^0 K^+) = P'[1 - (e^{i\gamma} - qe^{i\phi})r_{\rm c}e^{i\delta_{\rm c}}], \tag{28}$$

allowing us to study the $R_{\rm c,n}$ and the relevant $B \to \pi K$ CP asymmetries as functions of q and ϕ. We find—as in [16]—that the data in Eqs. (18) and (19) cannot be described properly for the SM values $q = 0.69$ [19] and $\phi = 0$, in particular, $R_{\rm c} \sim 1.14$ and $R_{\rm n} \sim 1.11$. However, treating q and ϕ as free parameters, we obtain

$$q = 1.78^{+1.24}_{-0.97}, \qquad \phi = -(85^{+11}_{-13})^\circ, \tag{29}$$

and a generically small CP asymmetry in $B^\pm \to \pi^0 K^\pm$, in accordance with the data [1]. A strong phase ω in the EW penguin sector, which may be induced by nonfactorizable SU(3)-breaking effects [6], is found to be small, thereby giving us additional support for the use of the SU(3) flavor symmetry [1]. In contrast to [16], where larger direct CP asymmetries in the $B \to \pi K$ modes were favored, the determination of the hadronic parameters through the $B \to \pi\pi$ system and the introduction of the weak EW penguin phase ϕ now allow us to describe *any* currently observed feature of the $B \to \pi K$ modes and predict for $B_d \to \pi^0 K_{\rm S}$ [1]:

$$\begin{aligned} \mathcal{A}_{CP}^{\rm dir}(\pi^0 K_{\rm S}) &= 0.05^{+0.24}_{-0.29},\\ \mathcal{A}_{CP}^{\rm mix}(\pi^0 K_{\rm S}) &= -0.99^{+0.04}_{-0.01}. \end{aligned} \tag{30}$$

Recently, the BaBar Collaboration reported the results of $0.40^{+0.27}_{-0.28} \pm 0.10$ and $-0.48^{+0.47}_{-0.38} \pm 0.11$ for these direct and mixing-induced CP asymmetries, respectively [20].

Let us finally note that we may complement the $B \to \pi\pi$ data in a variety of ways with the experimental information provided by the $B_d \to \pi^\mp K^\pm$ modes, allowing us to determine γ as well. If we take also the constraints from the whole $B \to \pi K$ system into account, we find results for γ in remarkable agreement with the UT fits; i.e., we arrive at a very consistent overall picture [1]. In the future, $B_s \to K^+K^-$ will provide a powerful tool for the simultaneous determination of γ and (d, θ) [8].

The implications of enhanced Z^0 penguin diagrams with a large new complex phase for rare and CP-violating K and B decays were already discussed in [21–23], where model-independent analyses and studies within particular supersymmetric scenarios were presented. Here we determine the size of the enhancement of the Z^0-penguin function C and the magnitude of its complex phase through the $B \to \pi K$ data. Performing a renormalization-group analysis as in [16] yields

$$C(\bar{q}) = 2.35\bar{q}e^{i\phi} - 0.82, \qquad \bar{q} = q\left[\frac{|V_{ub}/V_{cb}|}{0.086}\right]. \tag{31}$$

Evaluating, in the spirit of [16,21,22], the relevant box-diagram contributions within the SM and using (31), we can calculate the short-distance functions

$$X = C(\bar{q}) + 0.73 \quad \text{and} \quad Y = C(\bar{q}) + 0.18, \tag{32}$$

which govern the rare K, B decays with $\nu\bar{\nu}$ and l^+l^- in the final states, respectively.

The central value for Y resulting from Eq. (29) violates the upper bound $|Y| \le 2.2$ following from the BaBar and Belle data on $B \to X_s\mu^+\mu^-$ [24], and the upper bound on $\mathrm{BR}(K_{\rm L} \to \pi^0 e^+e^-)$ of 2.8×10^{-10} from KTeV [25]. However, we may still encounter significant deviations from the SM. In order to illustrate this exciting feature, we consider only the subset of those values of (q, ϕ) in Eq. (29) that satisfy the constraint of $|Y| = 2.2$. If we then introduce the CP-violating weak phases θ_C, θ_X, and θ_Y and use Eqs. (32) and (31) , we obtain

$$\begin{aligned} |C| &= 2.24 \pm 0.04, & \theta_C &= -(105 \pm 12)^\circ,\\ |X| &= 2.17 \pm 0.12, & \theta_X &= -(87 \pm 12)^\circ,\\ |Y| &= 2.2\ \text{(input)}, & \theta_Y &= -(103 \pm 12)^\circ. \end{aligned} \tag{33}$$

This should be compared with the SM values $C = 0.79$, $X = 1.53$, and $Y = 0.98$ for $m_t(m_t) = 167$ GeV.

The enhanced function $|C|$ and its large complex phase may affect the usual analysis of the UT [13] through double Z^0-penguin contributions to ε_K and $\Delta M_{s,d}$, but as demonstrated in [1], these effects can be neglected. Inserting then the values of $|X|e^{i\theta_X}$ and $|Y|e^{i\theta_Y}$ listed in Eq. (33) into the known formulas for rare K- and B-decay branching ratios [26], we obtain the following results:

(a) For the very clean $K \to \pi\nu\bar{\nu}$ decays, we find

$$\begin{aligned} \mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) &= (7.5 \pm 2.1) \times 10^{-11}, \\ \mathrm{BR}(K_{\mathrm{L}} \to \pi^0\nu\bar{\nu}) &= (3.1 \pm 1.0) \times 10^{-10}, \end{aligned} \tag{34}$$

to be compared with the SM estimates $(7.7 \pm 1.1) \times 10^{-11}$ and $(2.6 \pm 0.5) \times 10^{-11}$ [27], respectively, and the AGS E787 result $\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = (15.7^{+17.5}_{-8.2}) \times 10^{-11}$ [28]. The enhancement of $\mathrm{BR}(K_{\mathrm{L}} \to \pi^0\nu\bar{\nu})$ by 1 order of magnitude and the pattern in Eq. (34) are dominantly the consequences of $\beta_X = \beta - \theta_X \approx 110°$:

$$\frac{\mathrm{BR}(K_{\mathrm{L}} \to \pi^0\nu\bar{\nu})}{\mathrm{BR}(K_{\mathrm{L}} \to \pi^0\nu\bar{\nu})_{\mathrm{SM}}} = \left|\frac{X}{X_{\mathrm{SM}}}\right|^2 \left[\frac{\sin\beta_X}{\sin\beta}\right]^2, \tag{35}$$

$$\frac{\mathrm{BR}(K_{\mathrm{L}} \to \pi^0\nu\bar{\nu})}{\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu})} \approx 4.4 \times (\sin\beta_X)^2 \approx (4.2 \pm 0.2). \tag{36}$$

Interestingly, the above ratio turns out to be very close to its absolute upper bound in [29]. A spectacular implication of these findings is a strong violation of $(\sin 2\beta)_{\pi\nu\bar{\nu}} = (\sin 2\beta)_{\psi K_{\mathrm{S}}}$ [30], which is valid in the SM and any model with minimal flavor violation. Indeed, we find

$$(\sin 2\beta)_{\pi\nu\bar{\nu}} = \sin 2\beta_X = -(0.69^{+0.23}_{-0.41}), \tag{37}$$

in striking disagreement with $(\sin 2\beta)_{\psi K_{\mathrm{S}}} = 0.74 \pm 0.05$.

(b) Another implication is the large branching ratio,

$$\mathrm{BR}(K_{\mathrm{L}} \to \pi^0 e^+ e^-) = (7.8 \pm 1.6) \times 10^{-11}, \tag{38}$$

which is governed by direct CP violation. On the other hand, the SM result $(3.2^{+1.2}_{-0.8}) \times 10^{-11}$ [31] is dominated by indirect CP violation. The integrated forward-backward CP asymmetry for $B_d \to K^*\mu^+\mu^-$ [23] is given by

$$A_{\mathrm{FB}}^{CP} = (0.03 \pm 0.01) \times \tan\theta_Y \tag{39}$$

and can be very large in view of $\theta_Y \approx -100°$.

(c) Next, $\mathrm{BR}(B \to X_{s,d}\nu\bar{\nu})$ and $\mathrm{BR}(B_{s,d} \to \mu^+\mu^-)$ are enhanced by factors of 2 and 5, respectively, whereas the impact on $K_{\mathrm{L}} \to \mu^+\mu^-$ is rather moderate.

(d) We have also explored the implications for the decay $B_d \to \phi K_{\mathrm{S}}$ [1] to find $(\sin 2\beta)_{\phi K_{\mathrm{S}}} > (\sin 2\beta)_{\psi K_{\mathrm{S}}}$. This pattern is qualitatively different from the present B-factory data [20], which are, however, not yet conclusive.

In the next couple of years, it will be very exciting to follow the development of the values of the observables considered in this Letter and to monitor them by using the strategies presented here and in [1].

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[1] A. J. Buras, R. Fleischer, S. Recksiegel, and F. Schwab, hep-ph/0402112.
[2] BaBar Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **91**, 241801 (2003).
[3] Belle Collaboration, K. Abe *et al.*, Phys. Rev. Lett. **91**, 261801 (2003).
[4] M. Beneke and M. Neubert, Nucl. Phys. **B675**, 333 (2003).
[5] http://www.slac.stanford.edu/xorg/hfag/
[6] A. J. Buras and R. Fleischer, Eur. Phys. J. C **11**, 93 (1999).
[7] M. Gronau *et al.*, Phys. Rev. D **60**, 034021 (1999).
[8] R. Fleischer, Phys. Lett. B **459**, 306 (1999).
[9] R. Fleischer and J. Matias, Phys. Rev. D **66**, 054009 (2002).
[10] H. Jawahery, http://conferences.fnal.gov/lp2003/.
[11] Belle Collaboration, K. Abe *et al.*, Phys. Rev. D **68**, 012001 (2003).
[12] R. Fleischer *et al.*, J. High Energy Phys. 05 (2003) 053.
[13] M. Battaglia *et al.*, hep-ph/0304132.
[14] A. J. Buras and R. Fleischer, Phys. Lett. B **341**, 379 (1995).
[15] A. J. Buras and R. Fleischer, Eur. Phys. J. C **16**, 97 (2000).
[16] A. J. Buras, R. Fleischer, S. Recksiegel, and F. Schwab, Eur. Phys. J. C **32**, 45 (2003).
[17] Y. Grossman, M. Neubert, and A. Kagan, J. High Energy Phys. 10 (1999) 029; T. Yoshikawa, Phys. Rev. D **68**, 054023 (2003); M. Gronau and J. L. Rosner, Phys. Lett. B **572**, 43 (2003).
[18] M. Gronau *et al.*, Phys. Rev. Lett. **73**, 21 (1994).
[19] M. Neubert and J. Rosner, Phys. Rev. Lett. **81**, 5076 (1998).
[20] T. E. Browder, hep-ex/0312024.
[21] A. J. Buras and L. Silvestrini, Nucl. Phys. **B546**, 299 (1999).
[22] A. J. Buras, G. Colangelo, G. Isidori, A. Romanino, and L. Silvestrini, Nucl. Phys. **B566**, 3 (2000); A. J. Buras *et al.*, Nucl. Phys. **B520**, 3 (1998).
[23] G. Buchalla *et al.*, Phys. Rev. D **63**, 014015 (2001); D. Atwood and G. Hiller, hep-ph/0307251.
[24] Belle Collaboration, J. Kaneko *et al.*, Phys. Rev. Lett. **90**, 021801 (2003); BaBar Collaboration, B. Aubert *et al.*, hep-ex/0308016.
[25] KTeV Collaboration, A. Alavi-Harati *et al.*, hep-ex/0309072.
[26] A. J. Buras, hep-ph/0307203.
[27] G. Isidori, hep-ph/0307014.
[28] S. Adler *et al.*, Phys. Rev. Lett. **88**, 041803 (2002).
[29] Y. Grossman and Y. Nir, Phys. Lett. B **398**, 163 (1997).
[30] G. Buchalla and A. J. Buras, Phys. Lett. B **333**, 221 (1994).
[31] G. Buchalla *et al.*, Nucl. Phys. **B672**, 387 (2003).